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Summary

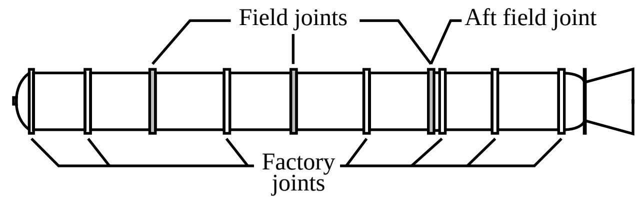
As a part of the redesign project of the Space Shuttle solid rocket motor (SRM) following the Challenger accident, the field joint was redesigned to minimize the relative joint motion caused by internal motor pressurization during ignition. The O-ring seals and glands for the field joint were designed both to accommodate structural deflections and to promote pressure-assisted sealing. A metal lip or "capture feature" was added to the field joint tang to stiffen the wall, thus minimizing joint deflection due to internal pressurization. Pressure ports were incorporated for the postassembly leak check tests of the joint to assess possible assembly damage and to seat the O-rings in their correct sealing position. Changes in the design specification also allowed for rougher surface finishes in the primary, secondary, and capture feature O-ring glands of the solid rocket booster (SRB) field joint.

Tests were conducted in various face seal fixtures to evaluate the ability of Viton V747-75 O-rings to seal for a range of temperatures and surface finishes of the redesigned O-ring gland. The effect of surface finish on the sealing performance and wear characteristics of the O-rings was evaluated during simulated launch conditions which included low-frequency vibrations, gap openings, and rapid pressurizations. The effect of contamination on the sealing performance was also investigated.

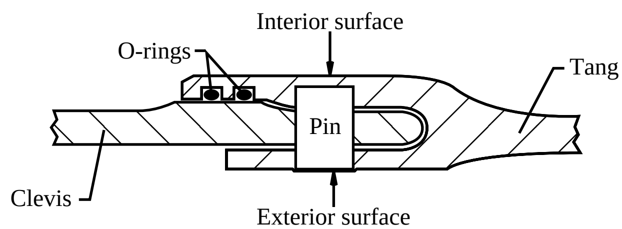
The O-rings sealed throughout the 75°F leak check test and for the seal tests from 50°F to 120°F for the range of surface finishes investigated. Although abrasions were found in the O-rings from pressurization against the rougher finishes, these abrasions were not detrimental to sealing. Below 50°F, Viton V747-75 O-rings were insufficiently resilient to track the test gap opening. The low-frequency vibrations from the strut loads had no noticeable effect on sealing, but the presence of a 0.002-in.-diameter wire across the O-ring caused an unacceptable leak.

Introduction

The Space Shuttle solid rocket booster (SRB) is composed of separate steel segments that are 12-ft-diameter cylindrical shells. (See fig. 1(a).) The case segments are mechanically fastened by using a clevis-tang joint, with each joint having two 12-ft-diameter continuous O-ring seals. (See fig. 1(b).) The SRB is partially assembled in the factory where two case segments are connected and a continuous layer of internal insulation is added. These joints are designated *factory joints*. The remaining four case segments of the SRB, which are assembled in the field, utilize two O-rings and are designated *field joints*.



(a) Space Shuttle solid rocket booster (SRB).



(b) Original field joint.

Figure 1. Schematic of Space Shuttle solid rocket booster (SRB) and detail of original field joint.

An investigation by the Presidential Commission on the Challenger accident concluded that "the cause of the Challenger accident was the failure of the pressure seal in the aft field joint of the Solid Rocket Motor." (See fig. 1(a) and ref. 1.) The Commission also stated that the elastomeric seals were severely affected (hardened) by the low temperatures at launch. Following an evaluation of the existing field joint design, further modeling and laboratory testing resulted in a redesign of the solid rocket motor (SRM) field joint (see fig. 2) in accordance with changes made to the Prime Equipment Contract End Item Detail Specification. (See ref. 2.)

The redesign of the SRM added a metal lip or "capture feature" to the field joint tang to stiffen the wall, thus minimizing joint rotation due to internal pressurization. The objective of the redesign was to employ multiple seals to ensure redundancy in sealing. The series of seals in the field joint included an additional O-ring that was added to the capture feature. (See fig. 2.) The three primary requirements for the seals in the redesigned SRM field joint were that (1) the seal must operate within a specified temperature range, (2) the O-ring seal must be capable of tracking twice the maximum expected gap opening or deflection without pressure assistance, and (3) the use of pressure assistance for sealing must be possible but not be required. The width of the gland was enlarged to incorporate the redesign requirement of

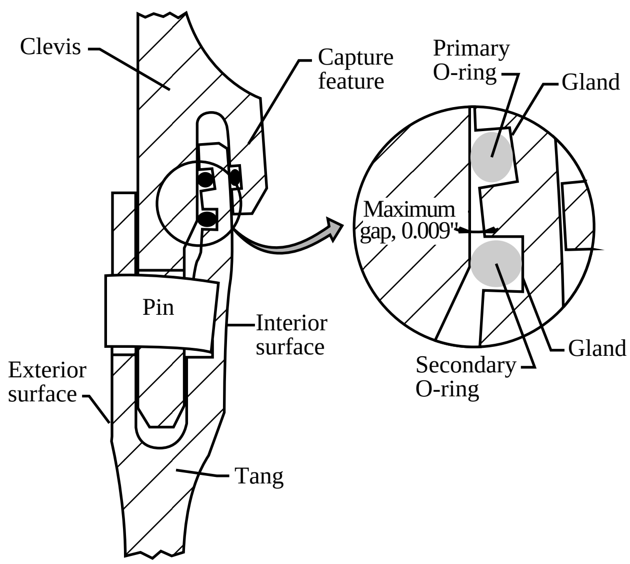


Figure 2. Schematic of redesigned field joint showing location of maximum gap opening during internal SRB pressurization.

accommodating but not requiring pressure-assisted sealing. The redesigned field joints also contained leak check ports for pressurization after assembly to properly position the O-rings while checking for leaks.

The surface finish specifications for the O-ring glands were relaxed from the industry standard of 32 roughness average (Ra) to a 63-Ra finish for the primary and secondary O-ring glands and to a 125-Ra finish for the metal lip ("capture feature") O-ring gland. The baseline O-ring material selected for the redesigned solid rocket motor was DuPont Viton V747-75, a fluorocarbon elastomer. (See refs. 3 and 4.) There was a concern that after sufficient times in compression, the O-rings would flow into surface asperities associated with machining and then, upon pressurization, abrade themselves as they were forced across the rough peaks of the machined grooves. These abrasions, if formed during the postassembly leak check tests of the joint and/or the motor ignition during launch, could lead to the detrimental formation of leak paths.

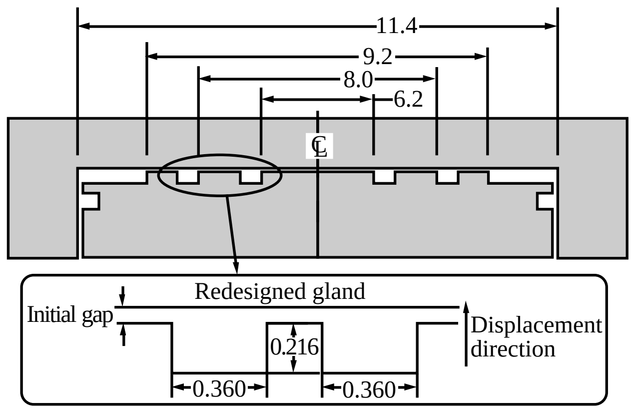
The two main sources of SRB joint structural deflections are the dynamic external tank (ET)/SRB attach strut loads during Shuttle launch and the internal motor pressurization of the SRB during ignition. The structural deflections associated with the attach strut are caused by the constraint of the SRB during Shuttle main-motor ignition. These constraint loads are stored within the assembled structure and released immediately after Shuttle launch. An analysis of previous flight data reveals that the structural vibrations caused by the attach strut loads produce maximum joint gap deflections of 0.001 in. at 3 Hz (private communication from Frank Bugg of the NASA Marshall Space Flight Center, Jan. 1987). The second source of deflection is the internal motor pressurization of the SRB. The 3σ case of the head end SRB motor pressure results in a maximum internal pressure of 1015 psi. This pressure creates a maximum gap opening (delta gap) of 0.009 in. between the clevis and the tang of the redesigned field joint, as shown in figure 2. (See ref. 5.)

An investigation was undertaken to examine the sealing and wear characteristics of the Viton V747-75 O-ring in the redesigned field joint gland. The effects of O-ring position and the presence of foreign objects on the sealing surfaces were also investigated. Tests were conducted in face seal fixtures with surface finishes ranging from 32 Ra (smoothest) to 250 Ra (roughest) at temperatures ranging from 20°F to 120°F. Testing followed the actual SRB leak check procedure to determine if leaks were present and to seat the O-rings properly. For the seal tests, the O-rings were monitored for pressure blowby while a computer generated the nonlinear displacement ramp, which incorporated the field joint structural deflections and vibrations associated with SRB ignition and Shuttle launch.

Test Equipment and Procedures

Tests were conducted in a series of laboratory-scale face seal fixtures which contained two glands that were fabricated with the cross-sectional dimensions of the redesigned field joint gland. (See fig. 3(a).) The prescribed O-ring gland surface finishes with allowed tolerances (in parentheses) for the face seal fixtures were 32 Ra (±10 Ra), 63 Ra (±15 Ra), 125 Ra (±40 Ra), and 250 Ra (±50 Ra). The allowed surface finish tolerances were designed to represent actual full-scale machining effects. The primary and secondary Viton test O-rings had nominal inner diameters of 8.022 in. and 6.272 in., respectively. The nominal cross-sectional diameter of both test O-rings was 0.290 in., which was the same cross-sectional diameter selected for the full-scale redesigned SRB O-rings. A new set of O-rings was used for each test. Figure 3(b) shows one of the fixtures mounted in a servo-hydraulic test machine. The face seal fixture squeezed the O-rings in a direction normal to the plane containing the O-ring.

During each test, normal forces on the O-rings were measured with a load cell while a direct-current



(a) Schematic of face seal fixture. All dimensions are given in inches.

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(b) Photograph of lower half of face seal fixture.

Figure 3. Face seal test fixture used for seal tests.

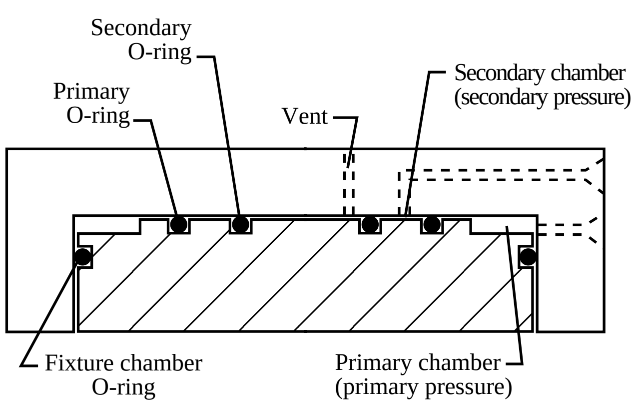


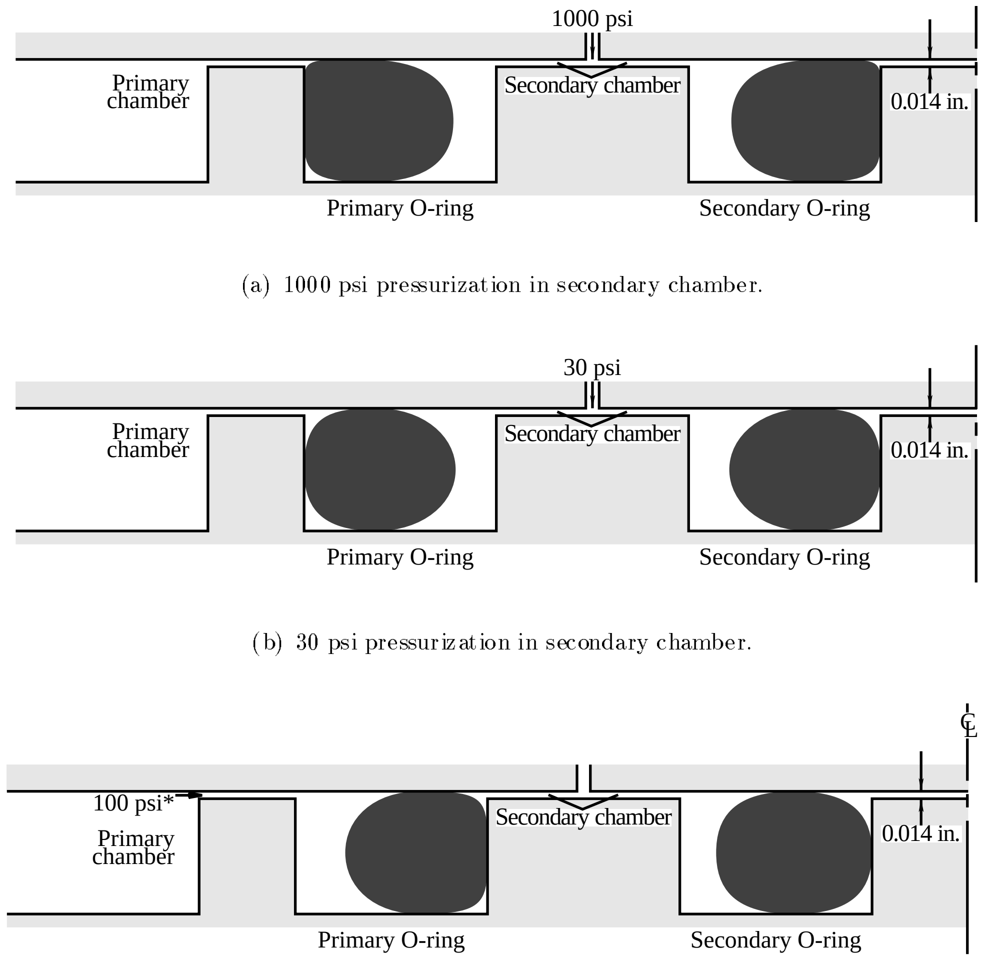
Figure 4. Schematic of face seal fixture.

displacement transducer (DCDT) measured the separation distance between the fixture halves. Pressure transducers were located ahead of the primary O-ring (primary chamber) and between the primary and secondary O-rings (secondary chamber) to monitor for pressure changes throughout the test procedure. (See fig. 4.) Thermocouples were used to verify that thermal equilibrium of the test fixture was maintained at the desired test temperature.

A calcium-based grease (Conoco Heavy-Duty No. 2) is used in the SRB O-ring glands for corrosion protection and O-ring lubrication. By using rubber gloves to prevent contamination, a minimal amount of grease was applied to the O-rings and fixture glands; the excess was then removed to leave only a thin residue. The O-rings were placed in the fixture glands and compressed to an initial gap separating the fixture halves that related to a given percent squeeze (the amount of diametrical compression) of the O-rings. The design assembly tolerances for the SRB clevis-tang field joint ranged from 0.004 to 0.014 in. Thus, the "worst case" condition for O-ring response was the minimum percent squeeze which corresponded to the maximum initial gap (0.014 in.).

The fixture halves were held at the 0.014-in. initial gap for prescribed periods of time and temperature to allow for viscoelastic relaxation. The O-rings relaxed to relieve the peak load resulting from the initial compression. This relaxation process was possible in the redesigned gland because when the O-rings were compressed, they were not constrained by the sidewalls of the gland. Although the relaxation period for these tests did not induce the permanent compression-set effects that SRB O-rings would experience during long-term storage after assembly, these short-term tests revealed the effect of surface finish on the seal and wear characteristics of the elastomer. "Compression set" is defined as the unrecovered deformation (as a fraction of the original squeeze) that the O-ring experiences after being held in compression for an extended period of time.

The actual SRB leak check procedure was used for these laboratory tests. This procedure was conducted at 75°F to check for leaks and to seat the O-rings in the sealing positions desired for launch. (See fig. 5.) The first step involved pressurization of the secondary chamber, venting the applied pressure, and then allowing the O-rings to relax for 30 min. A pressure of 1000 psi was applied between the O-rings while monitoring for pressure blowby in the primary chamber. (See fig. 5(a).) This pressurization seated the primary O-ring out of its correct sealing position and the secondary O-ring in its correct sealing position. However, at this extreme leak check pressure, the O-rings were somewhat deformed. After 30 min the pressure was vented and the O-rings were allowed to relax. The second step involved pressurization of the secondary chamber with 30 psi to check for pressure blowby when the O-rings were in a less deformed



(a) 1000 psi pressurization in secondary chamber.

(b) 30 psi pressurization in secondary chamber.

(c) 100 psi pressurization in primary chamber. Asterisk denotes omission in “Out” seal test.

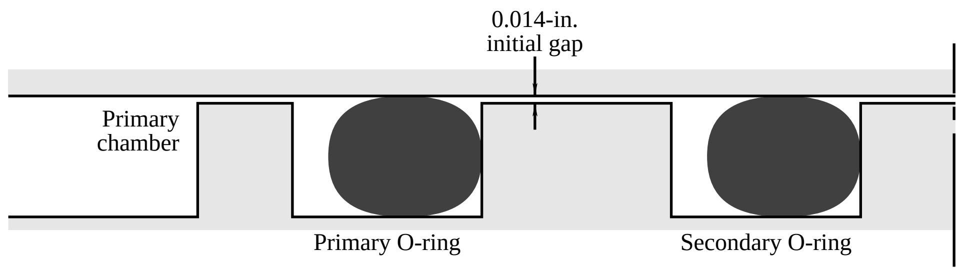
Figure 5. Schematic of O-ring position during leak check procedure.

state. (See fig. 5(b).) In the final step, 100 psi was applied to the primary chamber to seat the primary O-ring in its correct sealing position while the secondary chamber was monitored for pressure blowby. (See fig. 5(c).) After the leak check procedure was completed, the O-rings and test fixture were brought to the desired test temperature and held for 1.5 hr to allow for thermal equilibrium. The test fixture halves were maintained within ±0.5°F of each other for every test temperature.

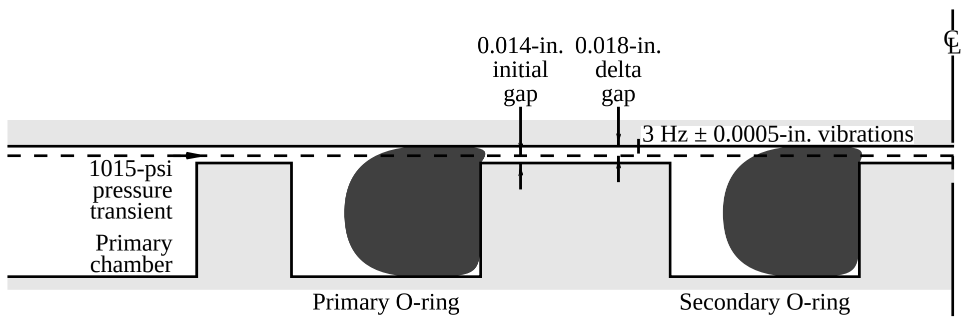
After thermal equilibrium was established, the seal tests were conducted, as shown in figure 6. During the seal test, the field joint structural deflections and vibrations corresponding to the SRB ignition and Shuttle launch were simulated, as shown schematically in figure 6(b). As shown in figure 7, a computer applied a nonlinear displacement ramp that simulated twice the maximum gap opening (0.018 in.) resulting from the 3σ pressurization of the SRB field joint. Simultaneously, a 3σ pressure transient was injected into the primary chamber. At the end of the 600-msec computer-generated displacement ramp, the vibrations (3 Hz ± 0.0005 in.) were added to determine the effects due to the ET/SRB attach strut loads for the duration of the test. Preliminary tests from this study indicated that the computer-generated test gap opening followed the projected SRB gap history very closely with a maximum deviation of ±0.001 in. The seal test duration was 2 min, which represented the total SRB burn time before being jettisoned from the Space Shuttle.

Seal Tests

Seal tests were conducted to evaluate the combined effects of abrasive wear, O-ring position, and temperature on the sealing performance of the



(a) Fixture at initial gap opening of 0.014 in.



(b) Application of pressure (1015 psi) and displacement histories. (0.018-in. delta gap and 3 Hz ± 0.0005-in. vibrations.)

Figure 6. Schematic of O-ring position during seal test.

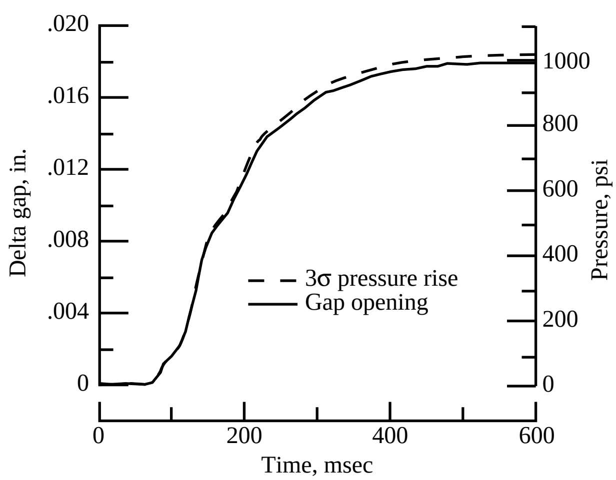


Figure 7. Actual SRB displacement history and 3σ pressure rise for redesigned field joint.

O-rings. The fixture halves were held at the 0.014-in. initial gap for 16 hr at 75°F prior to conducting the leak check procedure. Seal tests were conducted with the primary O-ring "In" and "Out" of its correct sealing position. The final step of the leak check procedure (100 psi of pressurization of the primary chamber) was omitted for the "Out" seal tests; thus upon pressurization, the primary O-ring must slide across the O-ring gland to seal. Both "In" and "Out" seal tests were conducted at the following test temperatures: 20°F, 30°F, 50°F, 75°F, and 120°F.

Long-Term Seal Tests

Long-term seal tests were conducted to evaluate the effects of long-term compression set and abrasive wear. The effect of compression set was simulated by holding the O-rings in compression at the 0.014-in. initial gap for 168 hr at 120°F to allow the material to flow into the surface asperities associated with machining. Then, the leak check and seal tests were conducted to determine the effect of abrasive wear on sealing. These tests were conducted at 75°F to eliminate temperature as a variable in the ability of the O-ring to seal effectively.

Foreign Object Seal Tests

The foreign object seal tests were conducted at 30°F, 75°F, and 120°F to assess the combined effects of abrasive wear, temperature, and foreign objects on the sealing performance of the O-rings. The fixture halves were held at the 0.014-in. initial gap for 16 hr at 75°F prior to conducting the complete leak check procedure. All foreign object seal tests were conducted with the primary O-ring in its correct sealing position with the addition of a 0.002-in.-diameter copper wire (approximately 0.5 in. long) placed over the O-ring as shown in figure 8. For comparison purposes, a single test was conducted with a human hair, a potential source of contamination, at 120°F for the 125-Ra surface finish fixture.

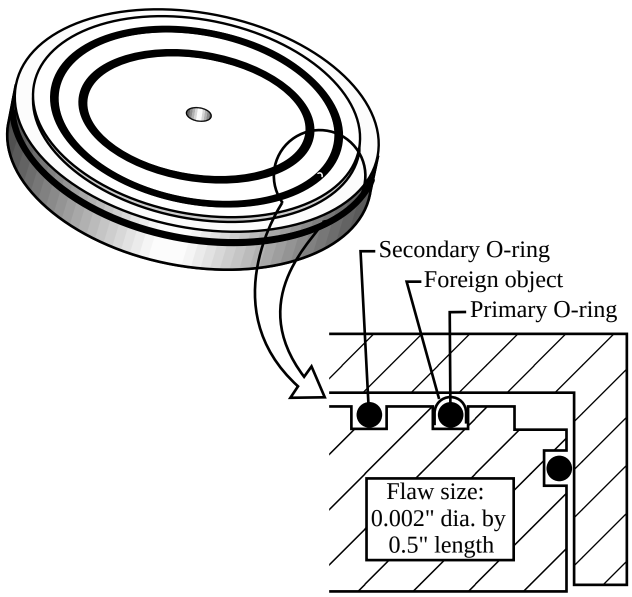


Figure 8. Foreign object location across primary O-ring.

Long-Term Foreign Object Seal Tests

Long-term foreign object seal tests were conducted at 75°F to assess the combined effects of abrasive wear, compression set, and foreign objects on the sealing performance of the O-rings. The O-rings were held in compression (at the 0.014-in. initial gap) at 120°F for 72 hr to simulate the long-term effects of compression set in the elastomeric material. Because of program constraints, a compression hold time of 72 hr was chosen instead of 168 hr to allow for duplicate testing of each surface finish. The long-term foreign object seal tests were conducted with the primary O-ring in its correct sealing position.

Discussion of Results

Seal Tests

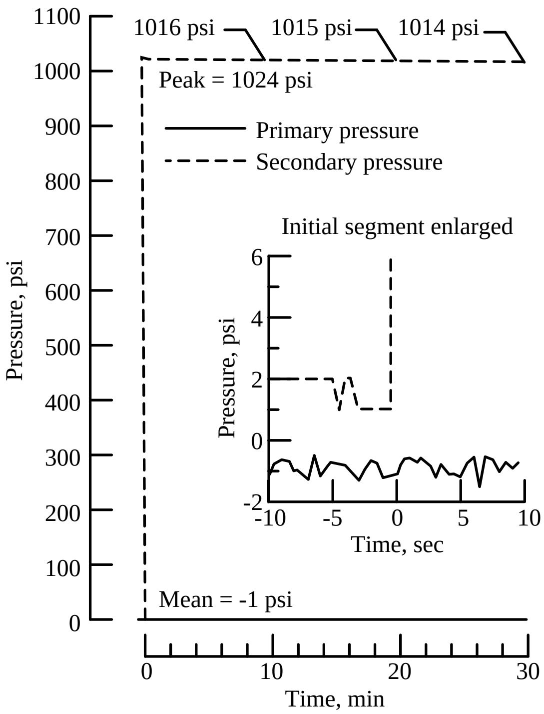
The seal tests examined the ability of the O-ring to seal twice the maximum expected gap opening (i.e., 2×0.009 in. = 0.018 in.) with the 3-Hz vibrations superimposed for each particular O-ring gland surface finish. The results of an assembly leak check procedure and an "In" seal test for the 32-Ra surface finish fixture at 20°F are shown step by step in figures 9 and 10, respectively.

Figure 9(a) shows the first step of the assembly leak check procedure that was conducted at 75°F when the O-rings were compressed in the fixture to an initial gap of 0.014 in. separating the fixture halves. For figures 9 and 10 the primary pressure is shown as a solid line and the secondary pressure is shown as a dashed line. The initial segment of the actual 1000-psi pressurization is shown enlarged to capture any instantaneous pressure blowby into the primary chamber. In this example, no pressure blowby into the primary chamber occurred. The pressure was then vented and the O-rings were allowed to relax for 30 min.

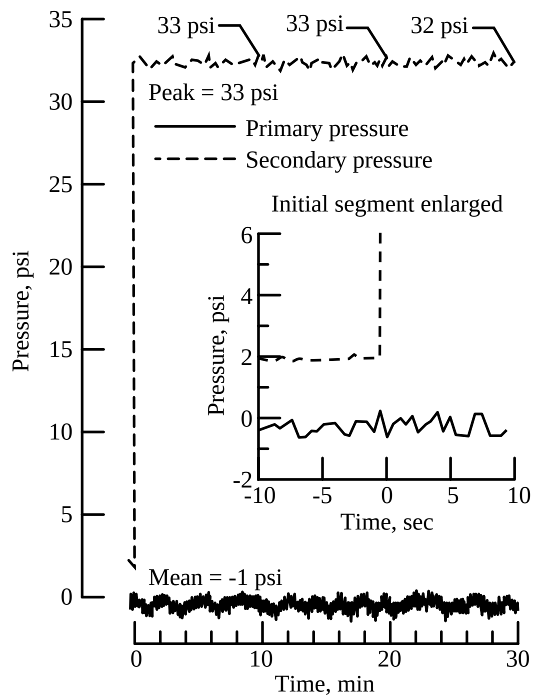
The above procedure was repeated with 30 psi to check for pressure blowby when the O-rings were in a less deformed state. (See fig. 9(b).) Again, no pressure blowby into the primary chamber occurred, thus indicating a successful sealing performance of the primary O-ring. Finally, 100 psi was applied to the primary chamber to seat the primary O-ring in its correct sealing position while the secondary chamber was simultaneously monitored for pressure blowby. (See fig. 9(c).) As shown in figure 9(c), the secondary pressure trace indicates that the primary O-ring sealed instantaneously. A small secondary chamber pressure indicates a successful seal. The slight pressure rise in the secondary chamber was caused by the movement of the primary O-ring toward the secondary O-ring, thus reducing the secondary chamber volume and increasing the secondary pressure prior to the gap opening. This pressure rise was previously observed in reference 3.

Next, thermal conditioning of the O-rings and test fixture was conducted for 1.5 hr to allow for thermal equilibrium. Figure 10(a) shows the displacement and pressure rise histories of the seal test conducted at 20°F. The primary and secondary chamber pressure traces of the seal test are plotted in figure 10(b). In the enlarged initial segment, the pressure blowby occurred instantaneously past the primary O-ring and into the secondary chamber, thus indicating an unsuccessful seal.

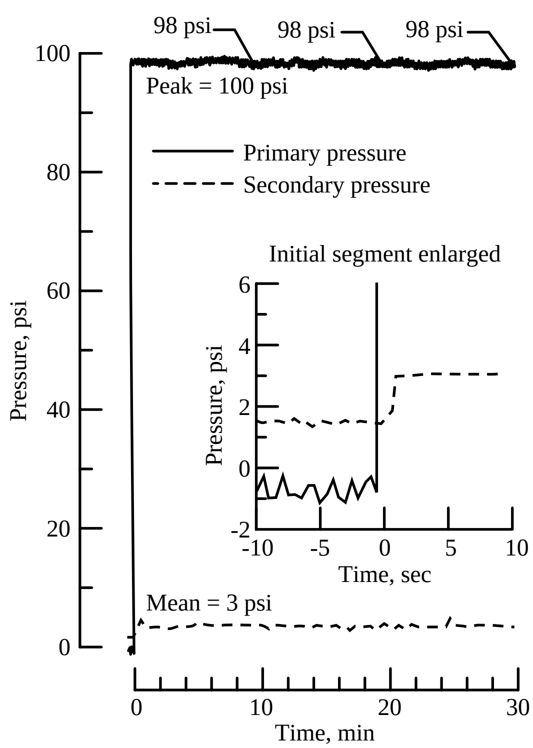
The results for both the "In" and "Out" seal tests are summarized in table I. Each data point reflects results from a single test. For all surface finishes and both primary O-ring positions, the O-rings instantaneously sealed for the test temperatures from 50°F to 120°F as indicated by the very small maximum secondary pressures (<5 psi).



(a) 1000 psi pressurization of secondary chamber.

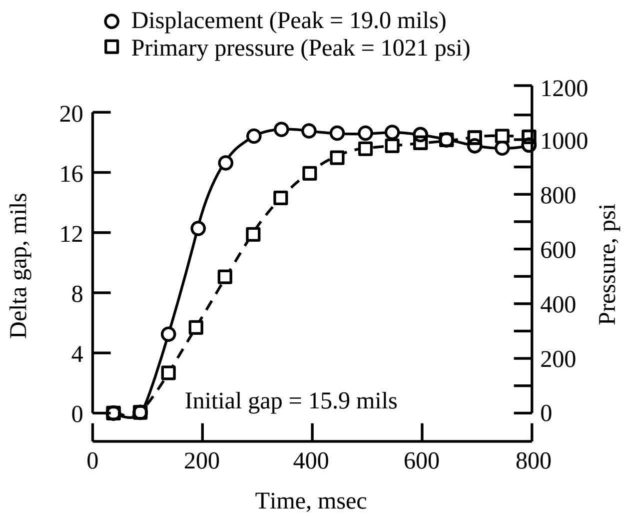


(b) 30 psi pressurization of secondary chamber.

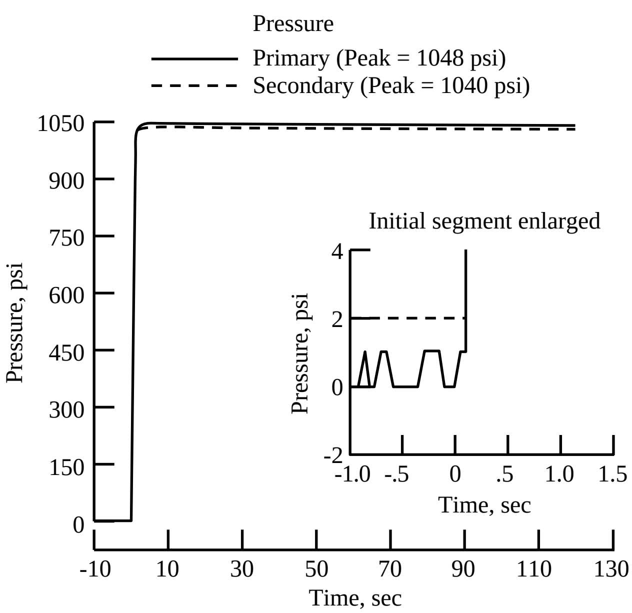


(c) 100 psi pressurization of primary chamber.

Figure 9. Leak check results for 32-Ra “In” seal test at 20°F.



(a) Displacement and pressure relationship during critical time period.



(b) Pressure traces of primary and secondary chambers.

Figure 10. Results of 32-Ra "In" seal test at 20°F.

At temperatures below 30°F, the tests generally resulted in either failures to seal or in delayed seals. (A delayed seal was considered unacceptable.) This result was attributed to the unresponsiveness of the O-ring to the fixture separation (gap opening), as had been previously shown in references 3–7. As the test temperature approached the glass transition temperature of Viton V747-75 (7°F to 12°F from ref. 8), the O-ring became stiffer and less rubber-like. Because of the effect of temperature on the O-ring sealing performance, the effects of surface finish and O-ring position could not be determined from these data.

Of the basic parameters that influence abrasive wear of polymers, surface finish and temperature have been previously shown to be very important (ref. 9). At the lower test temperatures, the O-ring becomes particularly brittle and abrasive forces more readily create microscopic surface fractures. Figure 11 shows the scanning electron microscope (SEM) photographs of the abrasive damage of 32, 63, 125, and 250 Ra at 20°F, and as expected, the severity of abrasions increased with the increase in surface finish from 32 to 250 Ra. Therefore, the worst case of abrasive wear (fig. 11(d)) was examined in closer detail. As can be seen in figure 12(a), the abrasive wear was characterized by periodic jagged cracks, parallel to the O-ring circumference and transverse to the direction of the O-ring movement. This type of abrasive pattern has been seen previously and described as Schallamach bands (refs. 10 and 11). Schallamach bands formed when the O-ring surface "stuck" to the asperities associated with the rough gland surface finishes until frictional forces were overcome by the pressurization of the O-ring. (See fig. 12(b).) Then, the O-ring tore free from the surface asperity and a fracture band appeared. This stick-slip mechanism was repeated to create the parallel crack pattern that was observed.

Although the O-rings were damaged by the rough surface finish at 20°F, the fracture bands were oriented parallel to the circumference of the O-ring surface (perpendicular to the direction of the applied pressure), and thus they did not result in leak paths. Failure to seal could occur only if the fracture bands extended across the O-ring cross-sectional contact area (ref. 12). Therefore, the abrasive wear seen in figure 11 was not detrimental to sealing, and the primary cause of seal failure was attributed to the lack of resiliency of Viton at lower temperatures. The redesigned SRB incorporated resistance strip heaters that maintained the O-ring joint temperature from 75°F to 120°F to ensure optimum sealing performance.

Long-Term Seal Tests

The results of the long-term seal tests are shown in table II. The O-ring was able to seal for the entire range of surface finishes examined, and thus the surface finish itself was not detrimental to the sealing performance of the O-rings. No significant difference was observed between the seal tests and the long-term seal tests. Thus, compression set effects, as simulated, were not a factor.

(a) 32 Ra.

(b) 63 Ra.

(c) 125 Ra.

(d) 250 Ra.

Figure 11. SEM photographs of abrasions on O-rings at ×330 during tests at 20°F with various gland surface finishes.

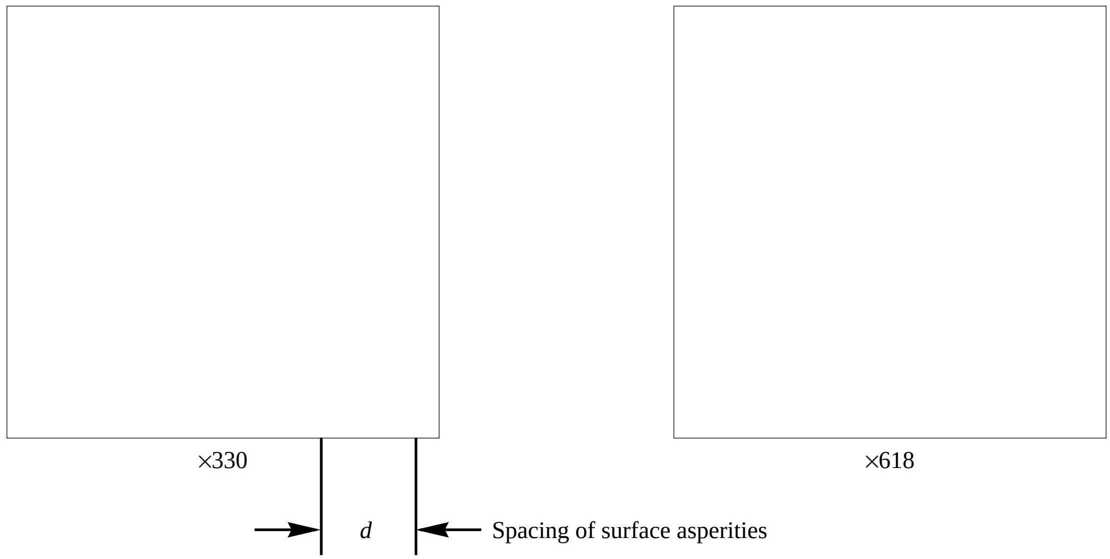
Foreign Object Seal Tests

For all surface finishes and test temperatures, the addition of a foreign object (a 0.002-in.-diameter wire) caused pressure blowby as indicated by the considerable secondary pressure increase shown in table III. The increase in pressure blowby past the primary O-ring indicated insufficient sealing of the primary O-ring. However, at the higher temperature of 120°F, the blowby was less severe than at the lower temperatures. The primary reason for this decreased pressure blowby was that at 120°F, the O-ring swelled around the foreign object (due to thermal expansion) which reduced the leak path size created by the wire. At the lower temperatures, the stiff O-ring did not expand around the foreign object and left a larger leak path across the O-ring, thus increasing pressure blowby.

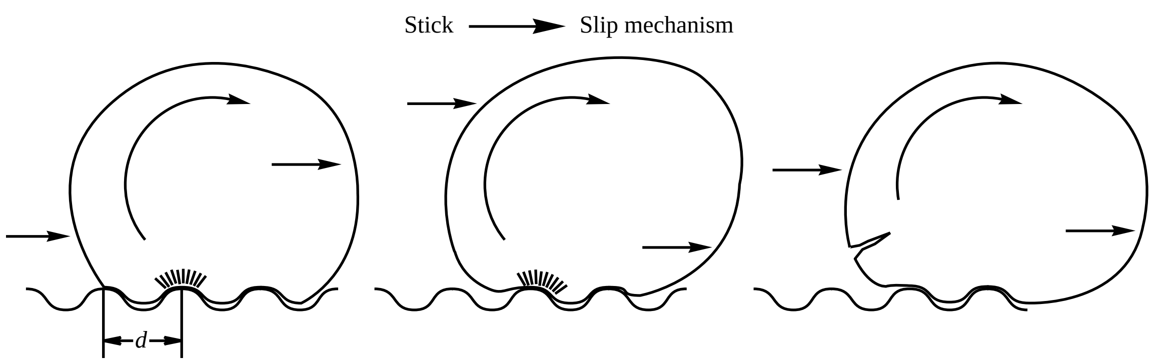
For comparison with the tests conducted using a wire (foreign object), a human hair of 0.00175-in. diameter was used with the 125-Ra fixture to examine the effects of an organic foreign object. Table IV shows that the addition of the hair caused a pressure blowby of 32 psi and the wire caused a pressure blowby of 69 psi, thus indicating that the amount of pressure blowby is dependent on the size of the foreign object. With either foreign object, the secondary pressure increase was significantly higher than the chamber pressures seen for the tests free of foreign objects.

Long-Term Foreign Object Seal Tests

For all surface finishes the addition of a foreign object (a 0.002-in.-diameter wire) caused pressure blowby as indicated by the considerable secondary



(a) Photomicrographs from "In" seal test of 250-Ra surface finish at 20°F.



(b) Schematic of stick-slip mechanism of abrasive wear.

Figure 12. Low-temperature abrasive wear characteristics.

pressure increase shown in table V. The pressure blowby past the primary O-ring indicated insufficient sealing of the primary O-ring. Differences in the data were likely due to variations in O-ring dimensions.

Concluding Remarks

Tests were conducted to evaluate the sealing ability of Viton V747-75 O-rings in the redesigned O-ring gland of the Space Shuttle solid rocket booster (SRB) for a range of gland surface finishes from 32 to 250 roughness average (Ra) and for temperatures from 20°F to 120°F. Both the effect of O-ring position in the primary gland and the presence of foreign objects were investigated. The tests were conducted by using face seal fixtures at the maximum internal pressure, gap opening, and gap opening rate projected for the SRB. The sealing ability of the O-ring was gauged by monitoring the chamber pressures for pressure leakage.

The test temperature had a much greater impact on the sealing performance of the O-rings than did the gland surface finish or initial O-ring position. Only the low test temperatures adversely affected the sealing ability in tests without foreign objects. At 30°F and below, satisfactory seals were not achieved because the O-rings did not track the seal test gap opening as a result of insufficient resiliency of the Viton elastomer.

The results of the long-term seal tests found that the surface finish was not detrimental to the sealing performance of the O-ring at 75°F. Scanning electron microscope analysis revealed abrasions on the surfaces of the O-rings that were attributed to pressurization of the O-rings across the rougher surface finishes. The high-temperature abrasion patterns formed were minor, but the low-temperature abrasion patterns were more pronounced and were seen as cracks parallel to the circumference of the O-ring. However, the crack orientation was along a benign direction and was not detrimental to sealing.

The results of the short- and long-term foreign object seal tests indicated that a 0.002-in.-diameter wire placed across the O-ring reduced the sealing performance of the O-rings throughout the range of test temperatures and surface finishes.

In conclusion, testing of the redesigned SRB field joint indicated that the test temperature affected O-ring sealing ability to a greater extent than either surface finish or O-ring position. The sealing performance was acceptable for all conditions (without foreign objects) above 50°F. Resistant strip heaters, which were added to the field joint redesign requirements, maintained the O-rings at an operating temperature of 75°F to 120°F to ensure optimum sealing performance. Testing showed that foreign objects degraded the sealing performance of the O-rings, even at the prescribed operating temperatures of 75°F to 120°F. However, testing also showed that the assembly leak check procedure was capable of detecting leaks prior to launch.

With the addition of the leak check ports in the field joint, we now have the capability of verifying O-ring sealing performance prior to launch. In case of unacceptable sealing performance, the joint can be disassembled, new O-rings can be installed, and then a new leak check can be performed.

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Table I. Results of Seal Tests

Temperature, °F	Maximum secondary pressure, psi, for—	
	"In" seal test	"Out" seal test
Surface finish = 32 Ra		
20	1040	1005
30	1009	999
50	1	2
75	1	1
120	1	2
Surface finish = 63 Ra		
20	4	1029
30	2	5
50	2	3
75	2	2
120	1	2
Surface finish = 125 Ra		
20	[a]35	1027
30	1	[a]119
50	1	1
75	1	2
120	1	3
Surface finish = 250 Ra		
20	[a]35	1
30	1	1023
50	1	1
75	1	1
120	1	2

[a]Delayed seal.

Table II. Results of Long-Term Seal Tests

O-rings held in compression at 120°F, hr	Surface finish, Ra	Maximum secondary pressure, psi
168	32	1
	63	2
	125	0
	250	0

Table III. Results of Foreign Object Seal Tests

Test temperature, °F	Surface finish, Ra	Maximum secondary pressure, psi
30	32	123
75	32	122
120	32	32
30	63	140
75	63	108
120	63	95
30	125	15
75	125	(a)
120	125	69
30	250	63
75	250	59
120	250	9

[a]Test not conducted.

Table IV. Effects of Foreign Objects on Sealing Performance for 125-Ra Surface Finish at 120°F

O-rings held in compression at 120°F, hr	Foreign object seal tests	Maximum secondary pressure, psi
16	Hair (0.00175-in. diameter)	32
	Wire (0.00200-in. diameter)	69
	No foreign object	1

Table V. Results of Long-Term Foreign Object Seal Tests at 75°F

O-rings held in compression at 120°F, hr	Surface finish, Ra	Foreign object seal tests	Maximum secondary pressure, psi
72	32	Wire (0.002-in. diameter)	15, 71
	63	↓	130, 114
	125	↓	25, 95
	250	↓	68, 73

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13. ABSTRACT *(Maximum 200 words)*
As a part of the redesign project of the Space Shuttle solid rocket motor (SRM) following the Challenger accident, the field joint was redesigned to minimize the relative joint motion caused by internal motor pressurization during ignition. The O-ring seals and glands for the field joint were designed both to accommodate structural deflections and to promote pressure-assisted sealing. Tests were conducted in various face seal fixtures to evaluate the ability of Viton V747-75 O-rings to seal for a range of temperatures and surface finishes of the redesigned O-ring gland. The effect of surface finish on the sealing performance and wear characteristics of the O-rings was evaluated during simulated launch conditions that included low-frequency vibrations, gap openings, and rapid pressurizations. The effect of contamination on the sealing performance was also investigated. The O-rings sealed throughout the 75°F leak check test and for the seal tests from 50°F to 120°F for the range of surface finishes investigated. Although abrasions were found in the O-rings from pressurization against the rougher finishes, these abrasions were not detrimental to sealing. Below 50°F, Viton V747-75 O-rings were insufficiently resilient to track the test gap opening.

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